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Geology. — *"On the Non-existence of Active Volcanoes between Pantar and Dammer (East-Indian archipelago), in Connection with the Tectonic Movements in this Region"*. By Prof. H. A. BROUWER. (Communicated by Prof. G. A. F. MOLENGRAAFF).

(Communicated in the meeting of January 27, 1917.)

It is a striking phenomenon that active volcanoes occur in all the islands of the Sunda-range Sumatra-Java-Bali-Lombok-Sumbawa-Flores-Lomblen-Pantar and do not exist farther on to the east in Alor, Kambing, Wetter and Roma, but reappear still farther eastwards in the curving chain of volcanic islands Dammer-Teon-Nila-Serua-Manuk-Banda.

According to VERBEEK [1]) the volcanoes of the Banda Sea form an ellipse separated from the volcanic Sunda islands by the "strip of older rocks", drawn by him across Wetter. In a paper on the recent mountain-building movements in this region [2]) we have designated the arch of volcanic islands in the Banda Sea, for the most part situated below the sea surface of the sea, as a continuation of the range of the Sunda islands. On this basis the non-existence of volcanoes in a certain portion of this chain must be accounted for as a phenomenon resulting from causes of a more general nature.

We enumerate, with reference to the volcanic phenomena, the following characteristics of the two curving rows of islands in the eastern part of the Indian archipelago.

a. The outer row (Timor-Tenimber-Ceram-Buru) is entirely devoid of volcanoes. These are to be found only in the inner row (Flores-Wetter-Dammer-Banda).

b. Occasionally the active volcanoes are also missing in the inner row, *just where the two rows approach each other most, i. e. to the North of Timor* (see Fig. 1).

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[1]) R. D. M. VERBEEK. Molukkenverslag Jb. v. het Mijnwezen 1908 Wet. Ged. Kaart N°. 1.

[2]) H. A. BROUWER, Over de bergvormende bewegingen in het gebied der boogvormige eilandenreeksen in het oostelijk deel van den O.-I. Archipel. Versl. Kon. Ak. v. Wet., Amst., Nov. 1916.

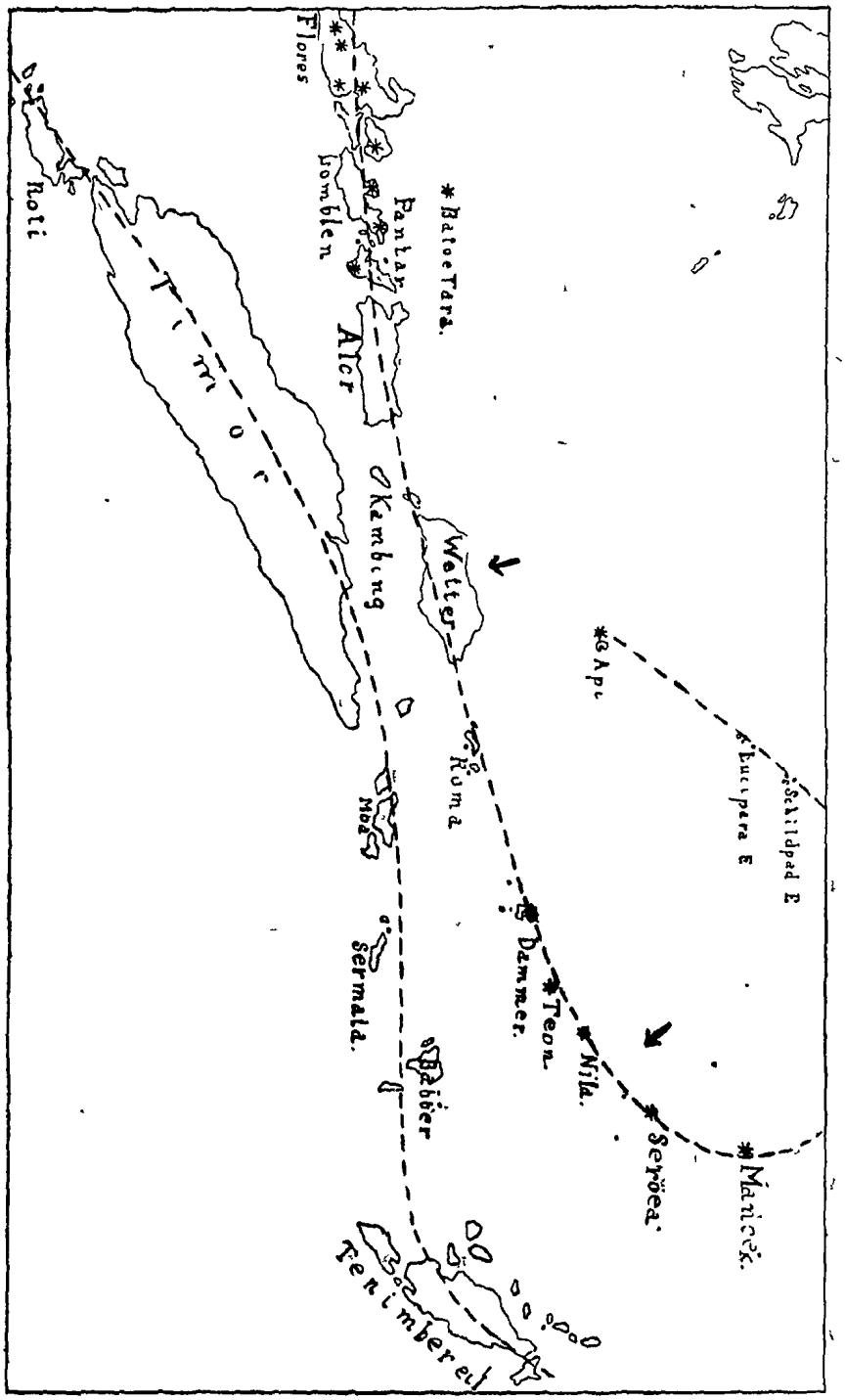

Fig. 1. Crustal movements and volcanic action in the South-eastern part of the East Indian Archipelago.

— — — — the geanticlines.

* centra of recent volcanic action.

c. Where active volcanoes do not exist in the inner row, products of extinct volcanoes cover a vast area. They also occur in the outer row (North coast of Timor).

The island of Lomblen still contains numerous, partly active volcanoes; in the eastern part of Pantar six independent vents of eruption are known, only one of which (the Gg Api) still displays the action of the solfatara-stage; the Delaki still exhibits a beautiful cone-shape, but at present is wooded to the very top. In the east of Alor there is an ancient volcano, the Peak of Alor [1]), 1655 m. high and to the south of it we find a second, lower peak; both have a cone-like shape, but through long erosion they have lost the beautiful regular appearance of a cone. Still farther towards the east we distinguish the old volcano of Pulu Kambing, north of Timor Dilli, farther again in Lirang and Wetter diabases, gabbros and granites have been laid bare by erosion over vast areas. Roma again consists entirely of volcanic products, tuffs, breccias, conglomerates and solid lava in dykes and flows [2]), however without active vents, which do not reappear again before Dammer, farther eastward.

It would seem then that, starting from Wetter; — where the two curving rows of islands are closest to each other — the volcanoes became extinct at a later period according as they were farther removed from Wetter. Lower down we shall discuss more fully *the relationship between the divergence of the rows of islands and a more prolonged volcanic action consequent on a progressing distance between the two rows.*

d. In those parts of the regions under consideration, where no active volcanoes occur, elevated coralreefs have covered extensive areas. In Pantar coral limestone covers all the older volcanoes up to a certain height above the sealevel (in this island 400 m.); only the young volcanoes Delaki and Iljasi Awieng with the still active vent Gg Api are not covered with limestone at their bases. [3]) In Alor the elevated reefs seem to reach a height of 700 m. above the sealevel, they likewise overlie the products of the slightly coniform Peak of Alor. More towards the east in the volcanic island of Kambing (± 1000 m. high) the volcanic products are covered by terraces of coral limestone to a great height (± 700 m.) [4]). Little is known as yet about the occurrence of elevated reefs in Wetter and Roma; in Wetter they occur along the coasts up to 80 or 100 m.

[1]) R. D. M. VERBEEK, l. c. p. 375.
[2]) Ibid, p. 435.
[3]) Ib., p. 15.
[4]) Ib., p. 376.

above the level of the sea and in Roma they [1]) have reached considerable heights. However, as far as the islands west of Wetter are concerned, our assumption, that volcanic action lasted the longer the more the islands were removed westwards from Wetter, is borne out by the occurrence of elevated coral reefs.

e. Whether there has been a shifting of the volcanic action in a direction perpendicular to the row of islands cannot be well made out.

It might be supposed, that it has shifted inward, because to-day volcanoes occur only in the inner row; but the present configurations of the landsurface resulted from the recent crustal-movements and the region north of the islands in fig. 1, is nowadays covered by the sea. The volcanic action may, in the tertiary period, have affected a broader tract, while at present it is confined to a narrower strip comprising the inner row of islands.

Having recorded these characteristics, we will now discuss first of all the origin and the shape of the two curving rows of islands.

Origin of the rows of islands.

In an earlier paper we have demonstrated [2]) that the elevation of the islands, encircled by deep ocean-basins, must be looked upon as a result of renewed mountain-building forces and that these movements, just as the tertiary, are apt to proceed towards the "Vorland". Their intensity has been variable, nor was it equal for various parts of one and the same row in a definite period, so that some parts may rise higher than the other and locally also subsidence may occur. We will confine ourselves to the region under consideration. In Timor a period of intensive crustal movements, persisting into the miocene, was succeeded by a prolonged denudation of the landmasses emerging from the sea. A large part of the island has afterwards been submerged again and a pliocene formation, whose oldest deposits consist of pure Globigerina-limestone devoid of terrigenous elements rests unconformably on the older formations, as has been discussed in detail by MOLENGRAAFF [3]) [4]). In plio-pleistocene

[1]) Ib., p. 435.

[2]) H. A. BROUWER, l. c.

[3]) G. A. F. MOLENGRAAFF, Folded mountain chains, overthrust sheets and block-faulted mountains in the East-Indian archipelago. C. R. XII[th] congr. geol. intern. Toronto 1913, p. 693

[4]) Ibid. On recent crustal movements in the island of Timor and their bearing on the geological history of the East-Indian Archipelago, Proc. Kon. Ak. v. Wet., 29 June 1902.

time a great part of Timor was still covered by a sea full of coral-islands and reefs, from which the higher mountains emerged as islands, similarly to what may still be observed farther eastward in the islands, east of Moa. Ever since a general elevation above the sealevel has been going on, which may still be proceeding. Signs of this uprise can be witnessed in all the islands of the region under consideration.

The foregoing points to a decrease of tangential pressure after the miocene process of mountain building and to a renewed intensification of that process in the plio-pleistocene, which possibly still continues.

Shape of the rows of islands.

For a more comprehensive exposition we refer to the map, accompanying our paper on the orogenetical movements in the discussed region [1] [2]; from fig. 1 it is, however, sufficiently evident that the outer row, in the part Rotti—Timor—Babber, has its concave side turned to the Australian continent, whereas the inner row is convex on that side. Again, the outer row exhibits outward bends in the Tenimber-islands and the Kei-islands, just where depressions occur in the "Vorland" (Australian Continent with Sahul bank and Arafura sea). The inner row does not bend in that way, the curve progresses regularly.

A comparison of the two curving rows of islands of the East-Indian archipelago will show, therefore, that *the outer row has better adapted itself to the shapes of the "Vorland" than the inner one.*

In the paper alluded to above we have compared the outward bends of the outer row in the Kei- and Tenimber-islands with the movement of the Pennine overthrust sheets of the Alps into the lower parts of the hercynian mountains against which they were forced upwards. The strong crustal movements in the miocene period have been rather weak in the Kei-islands; the eocene is not intensely folded in Groot-Kei, the miocene is not folded at all [3], while farther west the strata seem to be more strongly folded, as in a new island near Ut (Klein Kei-group) contorted, approximately vertical strata probably of eocene-marl and limestone, were observed. This indicates that the prolongation of the intensely folded and overthrust mountain range of the Timor islands in the direction of Ceram, did not yet show the marked outward bend near the Kei islands, and was

[1] H. A. BROUWER, l. c. Fig. 1.

[2] H. A. BROUWER. Ueber Gebirgsbildung und Vulkanismus in de Molukken. Geol. Rundschau VIII, 1917, p. 197.

[3] R D. M. VERBEEK, l. c. p. 501.

nearly parallel with the present inner row with the young active volcanoes.

The characteristics of the rows of elevated islands and of the deep seabasins between them are indicative of a renewal of the mountain-building process which, in the miocene period has pushed the mesozoic and anterior tertiary sediments in the direction of the "Vorland." They are not contrary to the assumption, that these movements take place again in the direction of the Vorland. When these movements persist, the rising of the islands will be attended with a removal in that direction, as e.g. was the case with the Kei Islands ever since the miocene movements. The sea-basins will then get narrower and the initial phase of the future overthrust sheets manifests itself on the surface as anticlinal and synclinal undulations in the direction of the Vorland.

Relation of volcanism to crustal movements.

The relation between eruptive activity and violent movement in the earth's crust, with regard to time as well as place, is a matter of general knowledge; geologists only disagree as to the cause of either. Volcanic outbursts constitute only one type of eruptive phenomena that require penetration of the earth's crust by the magma. In the case of folding movements the equilibrium will be restored by the coincidence of displacements in the crust with the movements of the molten magma.

With regard to the most recent crustal movements in the region under discussion, we assume that in the Moluccas they are connected with folding at a greater depth. If tangential pressure reveals itself in the formation of normal folds; the molten magma will, under compression from all sides, sometimes force its way through the crust with unequal strain, first of all near the tops of the anticlines, where tension takes place; active volcanoes may then appear on the top of the mountain chain (in our case the row of islands). The same holds good also for oblique folds, for the time the strata adhere to each other; it is evident, however, that for several reasons during the folding process the independent movement of the volcanic magma can be prevented, for example when fan-shaped folds are formed that blocked up a magma-reservoir.

In case of disruption the relations are different: the tension in the anticlininal and synclinal tops disappears or decreases and the vents of the volcanic magma leading to the surface, maintained by the tension, can gradually be stopped up.

Movements on a large scale will give rise to overthrust sheets, where one mass of rock has been pushed bodily over another; the earth's crust in situ will increase in thickness, an additional reason for the stopping up of the volcanic vent. A new way is opened for the magma to reach the surface along the thrust-planes; most often the magma, if it reaches the surface will appear on a lower level i.e. in the region here discussed below the surface of the sea along the outer margin of the row of islands and movements in the direction of the "Vorland" will cause the volcanic products to be gradually overlain by the moving masses.

Disruption of the strata may occur abruptly without any folding. It goes without saying that in this case there is no question about an exit for the magma on the tops of the anticlines; the disturbance of the equilibrium caused by the movements in the earth's crust are directly attended with an increase of thickness of the crust where the crustal movements take place. The above shows sufficiently that the magma can reach the surface while folding is in progress, but that the place where and the time when volcanic activity will appear, depend on the character of the crustal movements.

The magma can find an egress also without the aid of crustal movements. By assimilation of adjacent rocks or by magmatic stoping [1]) the magma can force its way upwards and extrude by de-roofing, as for instance DALY [2]) assumes for the rhyolite-plateau of the Yellowstone National Park, USSING [3]) for the Greenland intrusions and myself [4]) for the intrusion of the Pilandsberg in the Transvaal.

This volcanic activity may manifest itself particularly in the intermittent periods of rest of crustal movements. Secondly, the magma will only be able to penetrate through the crust in places where it is comparatively thin, because otherwise it will have cooled down too much and have lost much of its mobility. Consequently no effusion can be expected where the crustal movements have engendered a thickening of the earth's crust; this will then more likely be possible along the margins of the anticlines, particularly along the inner ones.

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[1]) R. A. DALY, Igneous rocks and their origin, 1914, p. 194.

[2]) Ibid, p. 122.

[3]) N. V. USSING, Geology of the country around Julianehaab, Greenland, Medde lelser om Gronland. Vol. XXXVIII and Mus. de Min. et de Géol. de l'Université de Copenhague. Comm. Geol. N°. 2. 1911.

[4]) H. A. BROUWER, On the origin of primary parallel structure in lujaurites. Proc. K. A. v. W., 8 Nov. 1912.

Ibid. On the geology of the Alkalirocks in the Transvaal. Journ. of Geol. XXV, 1917, p. 768.

When testing the above hypothetical considerations to the recent crustal movements in the region discussed, it appears that during these movements in the outer row of islands the magma has not reached the surface on the top of the geanticline. It is possible, however, that also there tangential pressure has revealed itself — anyhow initially — by folding without any breaking of the strata. So far as the present geological data enable us to judge, the same applies to the island of Wetter, close to the outer row of islands.

The volcanic rocks occurring along the inner margin of the row of islands i.a. in the north of Dutch-Timor and in Ambon [1]), are anterior to these crustal movements and perhaps were evolved by the anterior folding, which culminated in the miocene period. In the inner row of islands older but also young-volcanic rocks are found to a vast extent.

Volcanic action continues into the present time, but seems to extinguish gradually after having been intensified most likely with the renewal of the crustal movements. The volcanic activity was more prolonged consequent on a progressing distance from the outer row of islands, and from the "Vorland".

It would seem legitimate to assume that the folding movements were of the character described first in those parts that were nearest to the "Vorland", whereby the connection of the magma with the surface was broken. We refer to the above mentioned more complete adaptation of the outer row of islands to the configuration of the Vorland. The same will be the case in the islands east and west of Wetter, of the inner row, if the folding forces and the accompanying movements persist in the direction of the "Vorland". We see in the inner row of islands of the South eastern Archipelago an instance of *extinction of volcanic activity on the top of the geanticline during a renewal of the mountain building process.*

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[1]) Ibid. Geol. verkenningen in de oostelijke Molukken. Feestbundel Prof. Dr. G. A. F. MOLENGRAAFF, Verh. Geol. Mijnb. Gen. 1916, p. 38.

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(Communicated in the meeting of Jan. 27, 1917).

In VERBEEK's[1]) latest geological memoir on the Moluccas, eruptive rocks have been classified as follows:

1. *old basic igneous rocks* mostly of pre-permian age (azoic and palaeozoic). Some may possibly be mesozoic. Petrographically are distinguished peridotite, serpentine, gabbro, diabase porphyrite with their tuffs and breccias, diorite and diorite-porphyrite, the last two of minor significance, etc.

2. *granitic rocks* probably all of pre-permian age.

3. *old-meso-volcanic igneous rocks.* Older melaphyres, quartz-porphyries and quartz-porphyrites, probably also some diabases and diabase porphyrites. VERBEEK points out that no conclusive evidence has as yet been adduced to establish the age of the rocks classed among this group; he also surmises that part of them still belongs to the permian formation.

4. *young-meso-volcanic igneous rocks* (*cretaceous*), andesites, dacites and acid melaphyres with bronzite. Perhaps they belong partly to the old-meso-volcanic igneous rocks, another part may be even of old-tertiary age.

5. *tertiary igneous rocks* nowhere seem to go back to the eocene, because the nummulitic limestones are entirely devoid of debris of andesites, with which miocene sediments abound.

a. leucite- and nepheline rocks (old miocene or younger) considered to be the oldest group on account of the structure of the volcano Lurus in Java with an older rim of leucite basalt and a younger cone of hornblende-andesite.

b. old hornblende-andesites and biotite andesites with their tuffs and breccias (miocene). They have an individual existence, rarely do they constitute the base or the oldest rim of the large volcanoes of which some are still active. The latter cannot be separated from

[1]) R. D. M. VERBEEK. Molukken Verslag. Jaarb v. h. Mijnwezen 1908. Wetensch. Ged. p. 737 seqq. (Rapport sur les Moluques).